GINA – A Polarized Neutron Reflectometer at the Budapest Neutron Centre

L. Bottyán[1], D.G. Merkel[1], B. Nagy[1], J. Füzi[2], Sz. Sajti[1], L. Deák[1], A. V. Petrenko[3], G. Endrőczi[1], J. Major[1,4]

[1]*KFKI Research Institute for Particle and Nuclear Physics, H-1525 Budapest, P.O.B. 49 Hungary*
[2]*Research Institute for Solid State Physics and Optics, H-1525 Budapest, P.O.B. 49 Hungary*
[3] *Frank Laboratory of Neutron Physics, JINR, Dubna, Russia*
[4]*Max-Planck-Institut für Intelligente Systeme (formerly Max-Planck-Institut für Metallforschung), Heisenbergstr. 3, 70569 Stuttgart, Germany*

The setup, capabilities and operation parameters of the neutron reflectometer GINA, the recently installed "**G**razing **I**ncidence **N**eutron **A**pparatus" at the Budapest Neutron Centre, are introduced. GINA, a dance-floor-type, constant-energy, angle-dispersive reflectometer is equipped with a 2D position-sensitive detector to study specular and off-specular scattering. Wavelength options between 3.2 and 5.7 Å are available for unpolarized and polarized neutrons. Spin polarization and analysis are achieved by magnetized transmission supermirrors and radio-frequency adiabatic spin flippers. As a result of vertical focusing by the five-element (pyrolytic graphite) monochromator the reflected intensity from a 20x20 mm sample has doubled. GINA is dedicated to studies of magnetic films and heterostructures, but unpolarized options for non-magnetic films, membranes and other surfaces are also provided. Shortly after its startup, reflectivity values as low as $3x10^{-5}$ have been measured on the instrument. The facility is now open for the international user community, but its development is continuing mainly to establish new sample environment options, the spin analysis of off-specularly scattered radiation and further decrease of the background.

I. INTRODUCTION

A. Neutron reflectometry in materials nanoscience

The ever increasing need for product advancement and miniaturization keeps membranes, thin film assemblies, magnetic and non-magnetic multilayer and patterned heterostructures in the limelight of material science and technological development . In recent years more and more complex methods, instrumental and evaluation types have emerged to meet the new challenges. Due to the matching wavelength range of cold neutrons and their extreme sensitivity to the interface structure and to the internal magnetic fields, neutron reflectometry (NR) is a rather capable non-destructive method to investigate such nanostructures. Reflected intensity measured as a function of the momentum transfer Q_z, perpendicular to the sample surface provides information on the scattering length density (SLD) depth profile. Normalized reflectivities are usually recorded from unity in the total reflection regime to Q_z values of about 0.2 $Å^{-1}$, where the reflected intensity drops by five to six orders of magnitude. Layer thicknesses appear as regular features in the reflected intensity and may be modeled using optical formalisms[1,2]. Similar but spin dependent formalisms apply for polarized neutron reflectometry (PNR) in magnetic studies[3,4,5]. By fitting the appropriate model to the measured intensities as a function of Q_z, one can extract layer thickness, interfacial roughness, and depth-dependent scattering length densities, as well as magnetization profile. By measuring scattered intensity as a function of an in-plane wave vector component Q_x, one can, in addition, characterize lateral structures[6]. In the lateral direction, the interface may be rough on different length scales or may display a defined periodicity, resulting in diffuse scattering or Bragg reflections in Q_x scans, respectively. Polarized neutron reflectometry (PNR) not only provides an isotope-selective atomic depth profile (as well in the case of deeply buried layers) with a spatial resolution of a few nanometers[7,8], but it is also a highly sensitive magnetometry to determine the vector properties of the magnetization. The prototype polarized neutron reflectometer was developed and built at Argonne in the 1980s [9,10]. The increased interest in magnetic thin film analytical instruments triggered by the discovery of the giant magnetoresistance and related phenomena[11,12] resulted in a boom of PNR studies[13,14,15] as well as the construction of a number of new neutron reflectometers with polarization option at neutron sources across the globe. Here we report on the design, construction and operation parameters of the "Grazing Incidence Neutron Apparatus" (GINA) a recently installed neutron reflectometer at the Budapest Research Reactor (BRR)[16] of the Budapest Neutron Centre (BNC), Hungary.

B. The neutron source at the Budapest Neutron Centre

The research reactor at BNC is of tank type, it is moderated and cooled by light water. The area of the reactor hall, the first neutron guide hall (for the cold neutron instruments) and the second guide hall (for a thermal time of flight (TOF) instrument) are approximately 600, 400 and 120 m^2, respectively. Until the year 2009 the reactor was fuelled by 36% enriched ^{235}U. The core, which is surrounded by a solid beryllium reflector, is being converted and by January 2012 will be fully converted to 20% enriched Russian uranium fuel of type VVR-M2. The thermal power, the mean power density, the maximum thermal neutron flux and the maximum cooling water outlet temperature are 10 MW, 39.7 kW/litre, 2.1 x 10^{14} n/cm^{2}s and 60^{o}C, respectively. One reactor cycle at BNC lasts 10 effective days, which is followed by a short break for a weekend. The number of reactor-operation days per year varied from 156 to 165 in the recent years and similar figures are foreseen for the coming years[16]. The reactor has eight radial and two tangential beam tubes. On the tangential beam tube 10 the cold neutron source (CNS) is installed. Three neutron guides (10/1, 10/2 and 10/3) originating at the CNS provide cold neutrons to the facilities in the CNS Guide Hall (see Figure 1). REF, the first neutron reflectometer in BNC has recently been moved from cold guide 10/3 to 10/1 and is primarily used for quality test of neutron mirrors and other optical elements produced by Mirrotron Ltd., Budapest. The new GINA reflectometer is installed in the former position of REF on the cold guide 10/3, closest to the wall of the reactor building. The GINA facility occupies approx. 60 square meters including its well polished marble "dance floor" (25 m^2) and its control hutch.

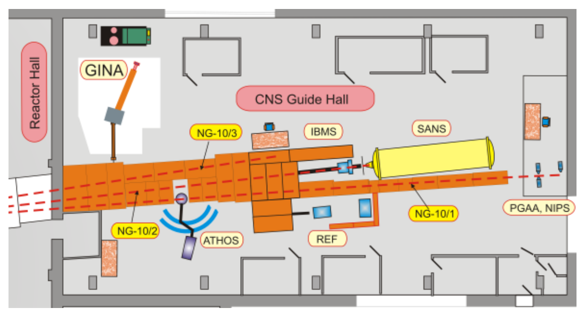

Figure 1. The layout of the CNS Guide Hall with the GINA instrument.

II. GENERAL OVERVIEW OF THE GINA INSTRUMENT

The GINA reflectometer is a constant-energy angle-dispersive instrument with a horizontal scattering plane[17]. The monochromator assembly, which is mounted in a gap of the cold neutron guide 10/3, selects the wavelength of the monochromatic beam within the range of 3.2Å – 5.7Å and can focus the beam in the vertical plane. In order to produce a polarized neutron beam, a magnetized polarizing supermirror (PSM) in transmission geometry and an adiabatic radio frequency (RF) spin flipper[18,19] are used. The beam scattered by the sample undergoes spin analysis by an identical setup of a spin flipper and a spin filter, and finally it is detected by a two-dimensional position sensitive detector. To reduce the background, the detector is encased in a B_2O_3-mixed polyethylene shielding and four motorized Cd-blade slits covered with B_4C rubber are provided in the beam path to discard the undesired neutrons, including those scattered from the device components. The complete instrument setup is shown in Figure 2. The neutron-optical devices of the reflectometer are mounted on two X95 optical benches[20] to provide precise definition of the beam height and a heavy-load support for various additional elements.

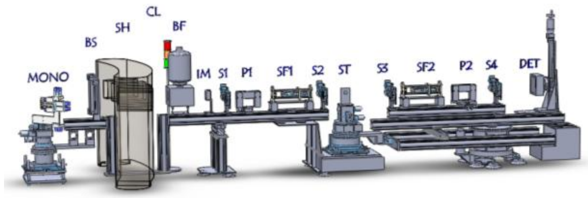

Figure 2. The layout of the GINA neutron reflectometer. The monochromator assembly (MONO) is mounted behind the concrete shielding (SH) on a turntable connected to the optical bench (B1) supporting the beam shutter (BS), (monitored by the semaphore control light (CL)), the intensity monitor detector (IMON), the cryostat of the beryllium filter (BF), the slit S1, the supermirror polarizer (P1), the adiabatic RF spin flipper (SF1) and the slit (S2). The bench is fixed to the central goniometer tower (ST1), the components of which define the position and orientation of the sample surface relative to the beam and supports the components of the sample environment. The optical bench (B2) is connected to the turn-table underneath the central goniometer tower and it supports the slit (S3), the spin flipper (SF2), the supermirror spin analyzer (P2), and the slit (S4) in front of the detector unit.

The bench B1 (cf. Figure 2) defines the horizontal optical axis of the reflectometer and supports the beam shutter, the intensity monitor detector, the cryostat of the beryllium filter BF, the slit S1, the polarizer P1, the spin flipper SF1 and the slit S2. Bypassing the radiation shielding by a U-shape construction, the bench B1 is connected to the turntable of the monochromator, a heavy-load goniometer with vertical axis. The axis of the turntable coincides with that of the monochromator. The angle of the optical axis relative to the guide and consequently the wavelength can be changed by manually rotating the entire GINA setup around the turntable while air pads are activated and the entire setup floats over the marble floor. The allowed wavelengths are restricted at present to 3.2, 3.9, 4.6, 5.2 and 5.7 Å by the respective channels through the cylindrical concrete shielding around the monochromator unit.

The downstream end of the bench B1 is fixed to the central goniometer tower ST1, the components of which define the position and orientation of the sample surface relative to the beam and supports the various sample environment components (electromagnet, cryostat, etc.). The X95 optical bench B2 – the 2θ-arm of the reflectometer – is connected to the sample turntable underneath the central goniometer tower and it supports the slit S3, the spin flipper SF2, the spin analyzer P2, and the slit S4 in front of the detector unit along with its electronics and dedicated control PC. The encoder-controlled precise motion around the turntable is performed by a rubber-coated motorized wheel under the stand ST2 while the air pads are pressurized (cf. Figure 2).

III. WAVELENGTH SELECTION AND FOCUSING

The monochromator is located five meters downstream from the cold source. The curved Ni/Ti supermirror neutron guide between the cold source and the GINA monochromator is of 340 m horizontal radius, 100 mm height and 25 mm width. The inner, outer, top and bottom mirrors are of $m = 2$, 3, 2 and 2, respectively. The TOF neutron spectrum of the beam leaving this guide section was measured by the pinhole camera technique[21] and the results are shown in Figure 3. The parameters of the experiment were: flight length: 3750 mm, pinhole diameter: 3 mm, chopper open time: 0.1 ms, bin time: 8 μs, detector gas absorption depth: 30 mm leading to a wavelength resolution of $\Delta\lambda/\lambda = 3.6\%$ at 4.6 Å and 6.2% at 2.3 Å.

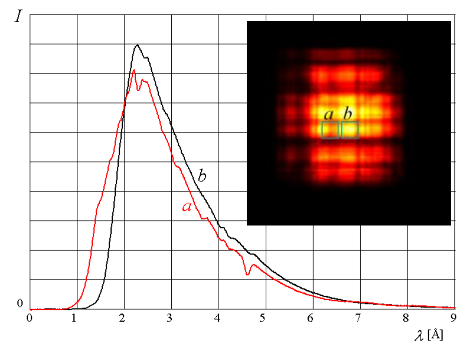

Figure 3 Neutron spectra of regions viewed by the pinhole camera technique through (*a*), and aside from (*b*) the GINA monochromator. Gaps at 4.6 Å and 2.3 Å are basic and first harmonic deflections by the monochromator graphite crystals. The difference between curves a) and b) are due to the neutron guide's Ni/Ti supermirror coating being viewed at different angles through the pinhole.

The monochromator assembly is mounted on a turntable connected to the optical bench B1 and comprises five highly oriented pyrolytic graphite (HOPG) crystals of $20 \times 20 \times 2$ mm^3, attached to thin horizontal Al alloy rods (Figure 4) and are lined up around the vertical axis.

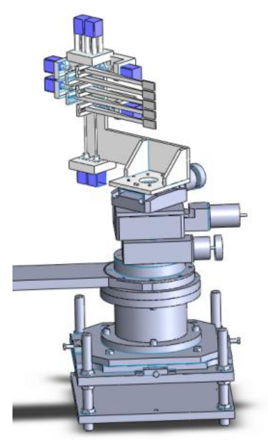

Figure 4. The monochromator assembly of the GINA reflectometer. Besides rotation, tilt and translation of the central graphite crystal (i.e. the full monochromator), the top and bottom two graphite crystals can be individually rotated and tilted relative to it.

The rod of the central graphite crystal is directly attached to the monochromator bench, which is alined with respect to the axis of the monochromator turntable and can be rotated around its vertical axis. The rods of the remaining four crystals (two above and two below) are attached to small motorized 2-axis goniometers for horizontal alignment and vertical focusing. Initial alignment and focusing of the graphite crystals was

facilitated by using a small chopper with a 1 mm diameter pinhole and a 2D detector in TOF mode to visualize the crystals (Figure 5). The wavelength calibration was performed by fitting a harmonic series to the peak positions in the TOF spectrum of the central crystal (see the spectrum without the Be filter in Figure 6a) thus calibrating the time channels in wavelength units. Vertical focusing to the sample position resulted in doubling the intensity reflected by a 2×2 cm^2 sample at grazing incidence as compared to the non-focused case of parallel graphite crystals.

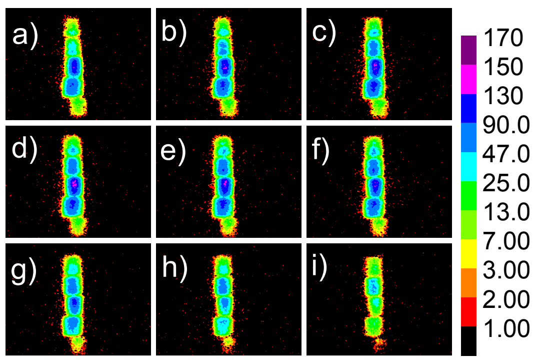

Figure 5 Intensity distributions of the reflections of the monochromator crystals focused on the sample position (2.5 m from the crystals) viewed at a distance of 2 m through a diaphragm of 1 mm diameter recorded by time-of-flight technique in different wavelength ranges of 0.03 Å starting from 4.46 Å – 4.49 Å (a) to 4.68 Å- 4.71 Å (i), respectively. The differences in brightness of the crystals is either due to their relative mis-orientation and/or the wavelength- and divergence-dependent intensity distribution in the neutron guide.

The entire monochromator assembly can be tilted around a horizontal axis. When the instrument is not in operation the monochromator assembly can be moved out of the beam using an *x*-stage. All eleven motions mentioned above are motorized and remotely controllable.

For the purpose of normalizing the measured reflectivity to the incident intensity, a low efficiency ^{3}He/CF$_4$ beam monitor detector[22] with an active area of H×W=100×42 mm^2 is mounted in the beam path downstream of the monochromator assembly. The detecting efficiency of the intensity monitor is ≈0.1% for λ=4.6Å neutrons.

Bragg reflections by the HOPG crystals contain higher harmonics according to the energy distribution of the incident neutron beam. These fractional-wavelength neutrons need to be filtered out from the beam incident onto the sample. GINA is equipped with a Be filter with Be-slab size of (height×width×depth) 72×42×150mm^3 which is cold-finger-cooled by liquid nitrogen during regular operation. The transmission of the filter was measured using the TOF technique with a wavelength resolution of 6%. This experiment revealed that the filter has a transmission of 40.7% and 86.6% for λ=4.6Å, without and with liquid nitrogen cooling, respectively, while suppressing all higher harmonics at both temperatures (Figure 6).

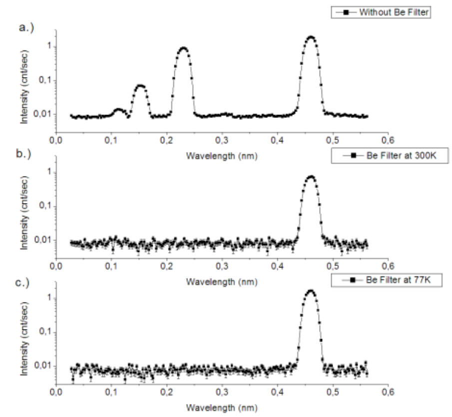

Figure 6. Area-integrated TOF spectrum of the detector pictures shown in Figure 5 taken in the parallel-aligned orientations of the HOPG crystals without Be filter (a), and with Be filter at 300 K (b) and 77 K (c). The higher harmonics are suppressed by the filter at both temperatures. The transmission of the Be-filter is 40.7% and 86.6% for λ=4.6 Å at 300 and 77 K, respectively.

IV. SPIN POLARIZATION AND ANALYSIS

In order to produce polarized neutrons an Fe-Co/Si magnetic supermirror (PSM) is used. The vertically oriented supermirror is mounted onto a rotator and a translator for adjustment to optimum polarization efficiency (defined below). The supermirror is placed between yokes of a permanent magnet construction with an in-plane vertical magnetic field of 30 mT. For spin analysis of the reflected beam, a single SM analyzer is used in an identical construction with the polarizer. By this setup, spin analysis of specular scattering is easily possible. In the case of off-specular scattering detailed studies are also possible but the experiments are rather time consuming. Both supermirrors are used in transmission geometry. The corresponding aggregate (P1×SF1×SF2×P2) flipping efficiency as a function of the position along the beam path is shown in Figure 7.

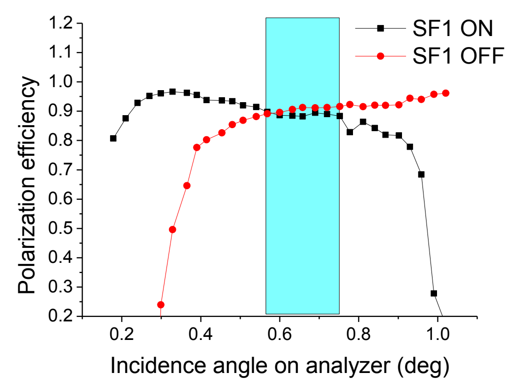

Figure 7. Polarization efficiency of the GINA setup *vs* the incidence angle on the PSM of the analyzer P2, with SF1 ON and OFF, respectively, while SF2 was kept OFF if both cases. The overall polarization efficiency is ~0.895 in the optimum angular range of operation which is marked by the rectangle.

In neutron reflectometry the signal to background ratio is always a critical parameter and has to be maximized. Being

limited in intensity, suppression of scattering of neutrons by the beam-line components is the key issue. Therefore, instead of using Mezei-flippers of simpler construction (always wires in the beam) we decided to opt for adiabatic RF spin flippers[18,19]. The flipper coil is placed in a transversal magnetic field with longitudinal gradient, produced by two iron plates energized by Nd-Fe-B permanent magnet stacks upstream and shunted by soft iron rods downstream. The coil is part of a serial electric resonant circuit, with a sinusoidal current and bandwidth (full width at half maximum, FWHM) of I_{eff}=4 A and 4.5 kHz at the resonance frequency of 175 kHz. The RF current is provided by a remote controlled power supply[23]. The parameters of the adiabatic RF spin flippers are summarized in Table 1. The flipper efficiency is better than 99% at any wavelength above 2 Å. The static field and the simulated projection of the neutron's magnetic moment to the static field is shown in Figure 8 as a function of the position along the beam path.

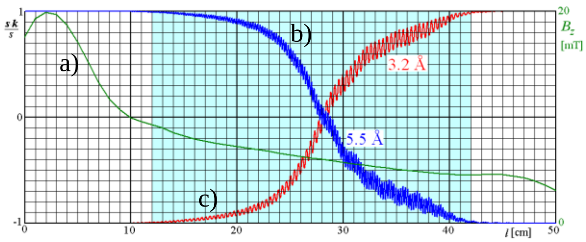

Figure 8 Parameters of the adiabatic radio-frequency spin flipper of GINA. The measured static transverse gradient magnetic field, B_z (a) and the simulated evolution of the projection of the neutron magnetic moment onto the field direction ($s \cdot k/|s|$) *vs* the position along the coil axis for spin-up and spin down neutrons of 5.5 (b) and 3.2 Å (c) wavelengths, respectively. Simulation parameters are summarized in Table 1.

For neutron spin analysis an identical set of adiabatic RF spin flipper and PSM is placed downstream to the sample. The overall polarization efficiency of the setup was determined by measuring the reflected and transmitted intensity on the analyzer P2 with and without activating the spin flipper SF1, while the second flipper was kept OFF. The polarization efficiency was calculated by the formula

$$P = \left(I^+ - I^-\right) / \left(I^+ + I^-\right) \qquad (1)$$

Where I^+ and I are the corresponding reflected and transmitted intensities by the analyzer P2. This yields an overall efficiency of 0.895 for P1, SF1 and P2.

V. SAMPLE POSITIONING

The flat sample is mounted on an adjustable vertical flat surface attached to the top cradle of the central goniometer tower. The sample mounting depends on the sample environment. For room temperature reflectivity measurements the flat surface has a small bore through which the sample is sucked to the vertical surface and held in position during the experiment by a small

TABLE I. Parameters of the adiabatic RF spin flippers

Parameter	Range
Resonant RF circuit	
Wavelength range	3.1÷5.8 Å
Beam height	60 mm
Frequency:	175 MHz
Coil length/diameter:	300/60 mm
Number of turns:	100
Inductance/Capacitance:	0.095mH/8.8nF
Peak-to-peak voltage/current	10A/1040V
Magnetic circuit	
Magnet block (Nd-Fe-B) 2×	60×50×20 mm^3
Yoke (L×W×H) 2×	500×100×12 mm^3
Magnetic field in the center	5.6 [mT]
Longitudinal gradient	0.2 – 0.4 [mT/cm]

vacuum pump. In such a way undesired scattering by the fixing elements is minimized. Symmetrical sample positioning is ensured by using two cradles and two perpendicular linear stages. The cradles and translators position the sample in the vertical plane and set the sample surface orientation. The θ and 2θ angles are encoder controlled for increased precision. Fine positioning of the beam is maintained by several slits with cadmium blades. The blades are extended and covered with B_4C-containing rubber to absorb undesired neutrons. The slits can be opened in the range of 0 to 10 mm with a precision better than 0.2 mm. One slit is placed downstream of the Be filter and one downstream of flipper SF1, just upstream of the sample. The slit S1 defines the beam on the polarizer mirror to decrease the beam divergence thus to increase the polarization ratio. Slit S2 decreases the beam divergence on the sample and absorbs the neutrons scattered off by the polarizer. With these optical elements the setup can achieve a relative Q-resolution of 10 to 2% for the available Q-range of 0.005 to 0.25 $Å^{-1}$.

VI. SAMPLE ENVIRONMENT

GINA is primarily dedicated to reflectometry of magnetic heterostructures[24]. For studies of magnetism, vital environmental parameters are (low) temperature and (occasionally high) external magnetic field. A closed cycle ^{4}He cryostat (comprising a cold finger setup[25] and evacuated by a small turbomolecular pump) can be mounted on the central goniometer tower of GINA with or without the electromagnet. The sample temperature can be varied in the nominal 9 to 300 K range[26]. The GINA beam line is equipped with an air-cooled electromagnet which produces magnetic fields up to 0.55 T for the pole distance of 40 mm that accommodates the 1.5" diameter Al cap of the cryostat. A water-cooled air core coil pair provides smaller magnetic fields up to approx. 35 mT.

VII. NEUTRON DETECTION AND BACKGROUND REDUCTION

For detecting the neutrons a multi-wire proportional chamber filled with $^3He / CF_4$ gas mixture of 2.5/3 bar partial pressures with 200×200 mm^2 active area and spatial resolution of

1.6 mm (FWHM). In order to suppress the background the detector is encased in a polyethylene shielding of 30 mm thickness containing 20w% natural B_2O_3. The two-dimensional spatial detection is managed by two delay lines and the positions are determined by a DASY TDC module (produced by ESRF, Grenoble) installed in a slot of the detector PC which is dedicated exclusively to the detector data acquisition and mounted on the 2θ-arm of the reflectometer. When detecting specular scattering, two slits (S3 and S4) are placed in front of the detector window to discard undesired radiation. If no spin analysis is required, for further background suppression, an evacuated flight tube is mounted along the entire length of the 2θ detector arm. Mounting the spin analyzer and flipper in a vacuum vessel is a plan for the future.

VIII. INSTRUMENT CONTROL

The GINA hardware and the control software are rather flexible and are designed for maximum remote controllability. In its full configuration GINA comprises more than 30 stepping motors[27]. Certain critical motions, such as θ- and 2θ-angles and precision slit positions are absolute or relative encoder-controlled. With the help of a custom made unit built around a USB multi-function data acquisition module[28]. The latter controls the air compressor, the pressurized air in the air pads, the nitrogen level and temperature in the Be-filter, the beam shutter and its control lights, the beam intensity monitor and the various modular DC power supplies (the latter ones to energize electromagnets, and various coils in the setup including optional Mezei flippers). The high voltage power supplies of the detector and that of the beam monitor, the linear amplifiers, the discriminators and the ratemeters are realized in modules of NIM standard. The control PC directly communicates with the detector PC via ethernet and with the indexer modules of the motion control units as well as with the temperature controller via RS232 lines. All listed components are controlled by the GINASoft control software written in LabView V10.0 for MS Windows. The user interface of the program allows for various alignment and scan modes as well as changing polarization and sample environment (flipper current and frequency, temperature, magnet current, etc.) remotely. For increased user comfort, the command format of the user interface is user-configurable, and includes a command format that resembles to that of SPEC[29]. 2D detector pictures and reduced reflectivity data can be efficiently viewed and manipulated during data acquisition. Collected and manipulated data as well as extended log information (including graphics) are saved in a clearly structured database format. Human control is facilitated by a web camera also installed on the control PC. Using remote desktop option, most operations can be performed remotely via internet from outside the experimental hall or even from a distant continent.

TABLE II. Operation parameters of the GINA beam line at the Budapest Neutron Centre

Parameter	Range
Wavelength	3.9÷5.1 Å in five steps
Present wavelength	4.6 Å
Max. scattering angle	≥θ=35°
Angular resolution ($\Delta\theta$)	0,003°
$\Delta\lambda/\lambda$	~1%
Background level	0.01 cps cm^{-2}
Detector	2D PSD of 200×200 mm^2
Detector resolution	1.6×1.6 mm^2
Neutron flux before monochromator	$4\times10^5 n\times cm^{-2}\times s^{-1}$
Background reflectivity	< 3×10^{-5}
Aggregate polarization efficiency of polarizer and analyzer SM	0.89

IX. DATA HANDLING AND EVALUATION

Users of the GINA reflectometer are offered the data handling and evaluation software FitSuite[30] a thoroughly documented program with a detailed project home page[31] written for Windows *and* Linux, and it is presently suitable for evaluating data of 14 methods, including specular polarized neutron reflectometry (with e.g. model for diffusion, also in isotope-periodic multilayers) and off-specular (diffuse) polarized neutron reflectometry (distorted-wave Born approximation) as well as specular x-ray reflectometry. Specular and off-specular reflectivities are calculated using the supermatrix approach[2]. FitSuite handles the corresponding theories and sample structures consistently in a common structure and allows for parameter restrictions, correlations and simultaneous simulation and fit of theories to the experimental data.

X. EXAMPLE REFLECTOGRAMS

Two example reflectograms are chosen to highlight the present performance of the GINA setup. The first one is the specular reflectivity of a 2-inch Si wafer measured in non-polarized mode. The data shown in Figure 8 were collected over a time of 22 hours. The fit (by FitSuite[31], full line) with nominal SLD and zero roughness provides a background reflectivity of 1.1×10^{-4}.

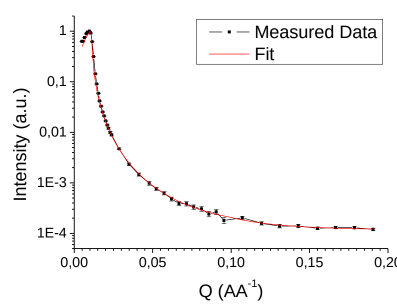

Figure 9. The specular reflectivity curve of a two-inch Si wafer measured on the GINA in non-polarized mode. The fitted background reflectivity is below 10^{-4}.

The second example is the specular reflectivity of a 20×20 mm^2 isotope-periodic multilayer[32] of MgO)001)/[Ni(15nm)/^{62}Ni(5nm)]$_5$ nominal layer structure measured in polarized mode. Aggregate data collection time was 56 hours. In Figure 9 the reflectivities R^+, R^- and spin asymmetry, $(R^+ - R^-)/(R^+ + R^-)$ are show in panels a), b) and c), respectively. The simultaneous fit to the measured R^+ and R^- with nominal SLDs and a collinear magnetization of 3 kG is displayed in full lines.

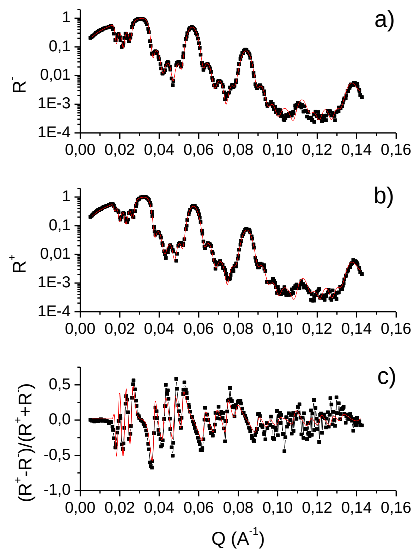

Figure 10. Measured R^+, R^- and derived $(R^+ - R^-)/(R^+ + R^-)$ specular reflectivities of an isotope-periodic multilayer MgO(001)/[Ni(15nm)/^{62}Ni(5nm)]$_5$ measured on the GINA reflectometer in polarized mode.

XI. SUMMARY

We have shown that GINA, the newly installed dance-floor-type constant energy angle-dispersive neutron reflectometer at the Budapest Neutron Centre is a versatile instrument in both polarized and unpolarized modes of operation. The sample orientation is vertical. The available sample environment facilities are: closed cycle cryostat optionally combined with external magnetic field by an iron core electromagnet up to 0.6 T or air core coils of 35 mT in various directions, spin polarization and polarization analysis by single supermirrors. Detection of diffuse scattering is facilitated by a two-dimensional position-sensitive detector. All components of the instrument are controlled by a program written in LABVIEW. The program allows for alignment and scan modes as well as changing polarization and sample environment parameters remotely. Reflectivities almost 5 orders of magnitude have been measured with further improvements underway. Further developments including an environmental cell for biomimetic membrane studies, an electromagnet with higher fields and orientation versatility and a supermirror fan analyzer and further background suppression elements are underway. The GINA reflectometer is open for Hungarian and international users throughout the year. All information concerning proposal submissions can be found at www.bnc.hu.

XII. ACKNOWLEDGEMENTS

The GINA team is grateful to Prof. H. Dosch, former director of Max-Planck-Institut für Metallforschung for his continued interest in the GINA project and for the transfer of a number of components of EVA, a former neutron reflectometer operated by the Max-Planck-Institut für Metallforschung at the Institut Laue-Langevin, Grenoble, France. Important support obtained from the members of the Stuttgart neutron group, namely A. Vorobiev and P. Falus, (Grenoble) and A. Rühm and J. Franke (Garching) is deeply appreciated. We are also grateful to T. Keller, (Max-Planck-Institut für Festkörperforschung, Stuttgart) for his continuous support in the later stage of the construction work. Helpful advises by Yu. V. Nikitenko (Frank Laboratory of Neutron Physics, JINR, Dubna, Russia) at an early stage of the GINA project are gratefully acknowledged. Authors are thankful for the electronic and mechanical design and construction work on GINA components to the colleagues at the KFKI Research Institute for Particle and Nuclear Physics, Budapest, in particular to P. Rusznyák, J. Gigler and G. Gy. Kertész, as well as the mechanical workshop team led by F. Bodai. The support of the management and staff of the BRR reactor of the Budapest Neutron Centre is gratefully acknowledged. This work was supported by the National Office for Research and Technology of Hungary and the Hungarian National Science Fund (OTKA) under contracts NAP-VENEUS'05 and K 62272, respectively. Mobility support for A.V. Petrenko by the bilateral project between JINR (Dubna) and the Hungarian Academy of Sciences is gratefully appreciated.

XIII. REFERENCES

[1] L.G. Parratt, *Phys. Rev.* **95,** 359 (1954).
[2] G.P. Felcher, *Phys. Rev. B* **24** (1981), p. 1595.
[3] L. Deák, L. Bottyán, D.L. Nagy, H. Spiering, *Physica B* 297, 113 (2001)
[4] A. Rühm, B.P. Toperverg, H. Dosch, *Phys. Rev.B* **60,** 16073 (1999).
[5] C.F. Majkrzak, *Physica B* **156-157** (1989), p. 619.
[6] S.K. Sinha, E.B. Sirota, S. Garoff and H.B. Stanley, *Phys. Rev. B* 38 (1988), p. 2297
[7] S. Krueger, *Curr. Opt. Colloid & Interf. Sci.* 6, 111 (2001)
[8] G. Fragneto-Cusani, *J. Phys.: Condens. Matter* 13, 4973 (2001)
[9] G. P. Felcher, R. O. Hilleke, R. K. Crawford, J. Haumann, R. Kleb, G. Ostrowski, *Rev. Sci. Instrum.* 58, 609 (1987)
[10] J.F.Ankner, G. P. Felcher, *J Magn and Magn Mater* 200, 741 (1999)
[11] Proc. 8th Int. *Conf. Surf. X-ray Neutron Scattering*, Physica B 357, (1-2) (2005) and references therein.
[12] Review articles in "*Nanomagnetism and Spintronics*" Ed. T. Shinjo, ISBN: 978-0-444-53114-8, Elsevier (2009)
[13] H. Zabel, *Materials Today*, 9, 42 (2006)
[14] H. Zabel, K. Theis-Bröhl, M. Wolff, B.P. Toperverg, *IEEE Trans. Magnetics*, 44, 1928 (2008)
[15] H. Zabel, K. Theis-Bröhl, B. P. Toperverg, in "*Handbook of Magnetism and Advanced Magnetic Materials*", Vol. 3 Edited by H. Kronmüller and S. Parkin, Wiley, New York (2007) ISBN: 978-0-470-02217-7
[16] L. Rosta, R. Baranyai,"Budapest Research Reactor – 20 years of international user operation" *Neutron News*, (2011) in print.
[17] B. Nagy, "*Installation of the GINA polarized reflectometer and its first applications to magnetic multilayers*" Diploma Thesis, University of Technology and Economics, Budapest 2010 (in Hungarian)

[18] A.N. Bazhenov, V.M. Lobashev, A.N. Pirozhkov and V.N. Slusar, *Nucl. Instrum. and Meth.* A 332, 534 (1993)

[19] S.V. Grigoriev, A.I. Okorokov and V.V. Runov, *Nucl. Instrum. and Meth.* A 384, 451 (1997)

[20] Newport Co., Irvine CA, USA, www.newport.com

[21] J. Füzi, *Nucl. Instrum. Meth. A* 586, 41 (2008)

[22] Canberra XERAM, type MNH 10/4.2 SCAL

[23] Flipper power supply type ANSFR-83C (Promel Unlimited, Budapest, Hungary)

[24] The construction of an environmental cell for studies of biomimetic membranes is underway.

[25] The cold finger cryostat is of Edwards CoolStar Coldhead 2-9 type, driven by an Edwards Cryodrive 3 He compressor

[26] Temperature control is performed by a Model 336 Lakeshore controller using standard Pt-100 and carbon glass sensors.

[27] The stepping motors are controlled by MCU-2FX and StepPack controllers from Advanced Control System Corporation, USA or SixPack 2 integrated controllers produced by TRINAMIC Motion Control GmbH, Germany.

[28] USB data acquisition module of type DT 9802, produced by Data Translation, USA

[29] SPEC by Certified Scientific Software, http://www.certif.com/

[30] Sz. Sajti, L. Deák, L. Bottyán, http://arxiv.org/abs/0907.2805v1.

[31] The URL of the project home page is http://www.fs.kfki.hu

[32] Sample prepared by molecular beam epitaxy in the MBE laboratory KFKI RMKI, Budapest